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Interoperability Modeling of the C4ISR Systems
La modélisation de l'interopérabilité des systèmes de commandement

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Abstract

Nowadays, as soon as a crisis or a small conflict is emerging throughout the world, coalitions of « responsible » nations are formed in order to solve it. The expected finality is to aim for an increased efficiency by coordinating their military means and technical systems. In merging these systems, we have to cope with a major problem, which is to make heterogeneous systems cooperate. This heterogeneity, inherent to national design and applications concepts, generates big deficiencies at the interoperability level. Since the solution of making gangways is not easily and reasonably generalized, the right thing to do is to provide all systems (entering in a coalition) with **interoperability mechanisms.** In this paper, we propose a formal approach which is relying on three main concepts : openness structure of a federation of systems, interoperability space with the definition of an interoperability matrix, intercooperability domain in which we are able to define parameters that allow us to assess interoperability

Résumé

Les nations sont de plus en plus souvent conduites aujourd'hui à former des coalitions, dès que se profilent de par le monde, soit des crises soit des conflits mineurs. Ceci, aux fins d'être plus efficace par la coordination de leurs moyens militaires respectifs et la réunion de leurs systèmes techniques afférents : réseaux, systèmes de commandement. La réunion de ces derniers, dès que l'on cherche à les faire coopérer, pose un difficile problème consécutif à leur hétérogénéité. La solution des passerelles n'est qu'une solution d'attente ne pouvant être raisonnablement généralisée ; aussi, convient-il, de doter ces systèmes de mécanismes d'interopérabilité. Dans cet article on propose une démarche formelle s'appuyant sur trois concepts principaux : structure d'ouverture pour une fédération de systèmes, espace d'interopérabilité et matrice d'interopérabilité, domaine d'intercoopérabilité.

Keywords : interoperability, cooperative systems, distributed systems, knowledge shareability.
***Mots-clés** : interopérabilité, systèmes coopératifs, systèmes distribués, connaissance partageable*

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1 Introduction and motivation

We often observe that more and more nations are often involved in international coalitions to face either crises or emerging minor conflicts. These coalitions are formed for the purpose of increasing efficiency, by the coordinated action of military means and the gathering of their relating technical systems : networks, C4IRS. Their merging generates situations that are at times technically new and complex. The major problem we have to cope with is to make the systems cooperate. In the cooperation's view, most of the time, they are **heterogeneous**; as a result, they present big deficiencies at the interoperability level. One could object that it is always possible, to solve this question by making gangways. In that case, one should be aware of what represents a temporary solution, and what is more, this solution cannot be easily and reasonably in a general use. What seems reasonable is to provide all systems of the coalition with **interoperability mechanisms** in order to obtain (inter)cooperation. We use the term **(inter)cooperate** intentionally to highlight the new

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needs differing completely from the simple exchange messages, as they can arise from the following statements :

- To exchange knowledge, whose the validity depends on time,
- To exchange know-how in operating processes and methods application.
- To contribute to elaborating tasks belonging to dynamic processes.
- To share, in timely and appropriate conditions, useful knowledge for the evolution and the action of other systems of the cooperation.

1.1 Cooperative framework of a coalition

A coalition is put in place to face an unusual situation relative to a crisis or upcoming conflict.

- A coalition aims at a goal in order to make the situation evolve in a way favorable to the partnership's interests.
- Systems put in the coalition are engaged to (inter)cooperate for executing a common mission, which has been established under particular conditions, with temporal constraints. Each system leads adequate actions as required by the mission.

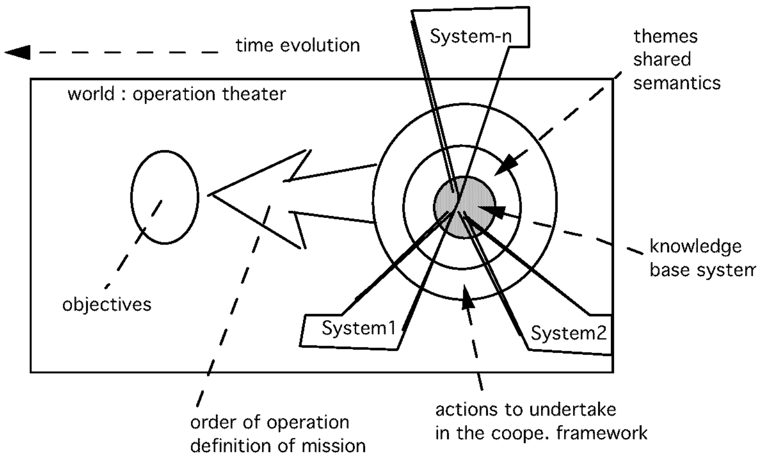


Fig. 1 Coalition framework

1.2 Cooperative system in a coalition

We will call **(inter)cooperative** system, a particular system that owns all criteria defining it as a system, and in addition has certain abilities when it is placed in a coalition framework :

Openness ability :
Quality of a system, previously connected with others, to share a common understanding with them, relative to some themes of a coalition, for instance : ground evacuation, medical assistance. As it will be shown later on, the openness of a system appears to be a subset of the structure openness of the coalition.

Interoperabllity ability :
Capability of a system to (inter)operate with (interoperable) actions, relevant to the cooperation, more precisely orders and missions fixed within the coalition. Characteristics may be attached to it : possibilistic measure, interoperable competence, matrix of interoperability.

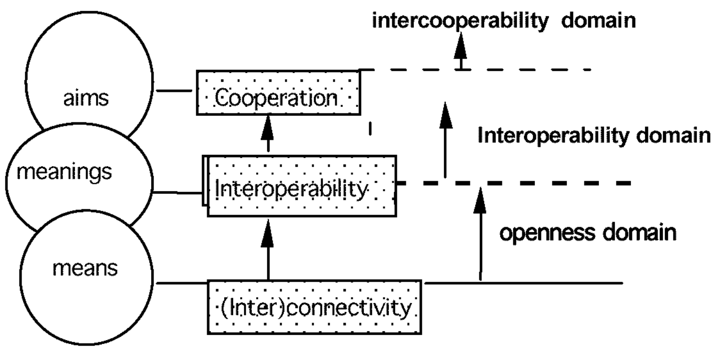
Intercooperability ability :
We will consider that a system is intercooperable when, it is able to share its knowledge but also know-how with its neighboring systems, in an optimal way, according to the comprehension it can get of the evolving situation.

Ability to conduct actions :
One admits that a system owns all the competence to do the required job in the coalition, and consequently, it can completely interoperate and furthermore intercooperate on all actions assigned to it. Of course this ability can fail if the conditions of temporal intervals are not strictly enforced; an action is only valid in a precise temporal interval.

In this paper, we will consider that C4IRS systems are belonging to the category of (inter)cooperative systems.

1.3 Formal approach basis

In our view, interoperability must be only considered as a **prerequisite of intercooperation**. In that scope, we will establish a clear distinction as in [Bares-1996], between three different domains that must be taken into account in such an approach. All systems that are put in relationship in the coalition must have certain criteria and characteristics which are defined in these domains. What's more, they are relevant of techniques and ways of modeling which are very different.



Let us describe briefly what we put in each of these three domains.

(Inter)connectivity:
This concerns essentially all necessary means to allow systems to communicate with each other, through a liaison and its relevant software mechanism. We will consider interconnectivity in our approach as a prerequisite of interoperability.

***Interoperability** :*
If we consider now that C4IRS systems must exchange more than simple messages, i.e., knowledge, we must go beyond interconnectivity framework, because the exchange of knowledge supposes that we have symbolic representations to carry this knowledge. Moreover, C3I systems in the future will be called upon, to bring each other a mutual assistance (a requisite in the NATO definition of C3IS) in their cooperative action to reach a common objective (called intercooperation later on). In such a perspective, C4IRS systems must be in position to have a mutual comprehension of what they are doing, of what processes they are running, and so on. At that point, we have to determine modalities that can obtain ''intelligence'' and how to interpret it, in the exchange mechanisms.

To sum up, we can characterize the interoperability domain by the following points :

- A C4IRS becomes interoperable when it can organize itself and enriches its exchanges within an **openness structure** characterizing the coalition.
- The precedent point represents a necessary but not sufficient condition in an interoperable exchange; in addition, we need to have a common vision of the universe in which systems are going to cooperate with others.
- To take into account semantics in the mechanism of exchange.

Intercooperability :
This represents the final objective to reach, through the definition of a world, in which all (cooperative) systems are able to share all elements constituting their common activity in the coalition, but also, to take systematically advantage of everything that is appealing to intelligent behavior.

2 Openness concept for a cooperative system

We feel the need to go beyond the simple concern about interconnectivity (and the simple fact of exchanging data and messages) in order to start to tackle the question of semantics, which will begin more required in interoperability. We must be able to have a basic understanding of what is taken into account in the exchange mechanism. The role of what is called in this paragraph **openness domain**, is to specify, beyond interconnectivity, ways and limits of opening which are necessary to have a basic interoperability.

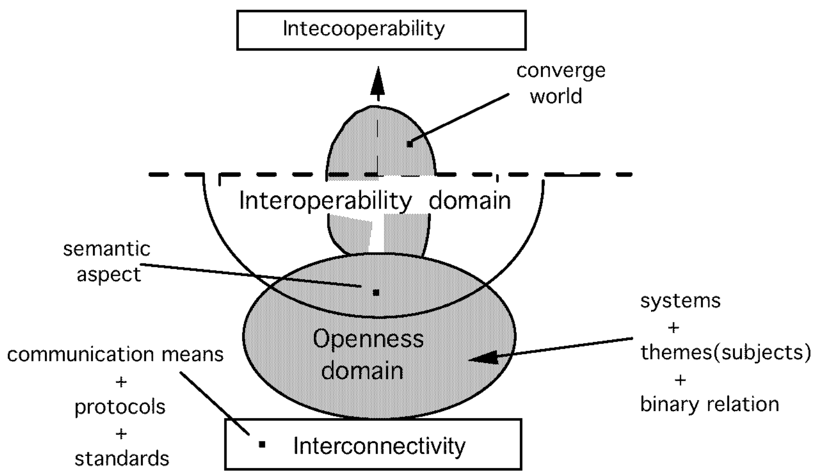


Fig. 3 Openness domain place in interoperability

We should first mention what systems and themes[1] are about to be concerned by missions relevant to the coalition/cooperation.

- *System in the coalition* : a system i will be designated by : $\mathbf{S^i}$ where $i \in [1, n]$, n = number of systems placed in the coalition. They are supposed to be able to share a minimum common knowledge and to have common comprehension of fundamental orders.
- Notion of theme : a theme of the coalition is a set of knowledge required for it and describing a speciality, a feature, an ability. **A theme** t will be designated by $\mathbf{T}_t$ with $t \in [1, q]$ (q is the number of themes of the coalition). $\mathbf{T}_t$ encompasses a variable number of elementary actions (depending on the mission). An action **j** will be designated by $\mathbf{A_j}$. These themes can be stated by syntactic formulas obeying the syntactic rules of a formal language.

[1] Here a theme must be considered like a set of (interoperable) actions.

2.1 Context of openness

We introduce now the concept of **openness context** to emphasize the semantic point that will be attached to themes and systems operating in the cooperation. We will formally define a context of openness by a triplet :

$$(S, T, R),$$

where : $S :: \{S^i\}_{i=1,2,\dots,n}$ the set of the (inter)cooperative systems,
$T :: \{T_t\}_{t=1,2,\dots,q}$ the set of the themes specified in the coalition,
R is a binary relation : $R \subset S \times T$.

The context may be given a priori when the coalition, put in place, is defining the mission of every system. It can be also defined a posteriori when the coalition is running and evolving.

Let us consider the following example : a US system S^1, a French system S^2, a German system S^3, which are supposed to interoperate within the framework of civil rescue in the Balkans. These 3 systems are competent on the 3 following themes : T_1 ground evacuation operations, T_2 airborne transportation, T_3 logistical medical aid; this supposes they are able to (inter)operate on different actions relevant to the themes and secondly to exchange knowledge required to achieve their respective missions.
Let us suppose we have all following couples :

$R(S^1, T_1),.., R(S^1, T_3), R(S^2, T_1),.., R(S^2, T_3), R(S^3, T_1),.., R(S^3, T_3) \subset S \times T$, that means :
the relation R on $\{S^1, S^2, S^3\} \times \{T_1, T_2, T_3\}$ is **total**

This openness context is summarized by the table :

Relation R	T1	T2	T3
S1	*	*	*
S2	*	*	*
S3	*	*	*

Tab. 1 Openness context example

Considering strictly the semantic point of view, systems are totally open to the themes involved in this coalition. This example describes a situation which is ideal and will rarely take place in reality. From a strict point of view, S^1, S^2, S^3 , must be considered as **totally open** on themes required in the coalition. Consequently, we get a unique totally open couple:

$$(\{S^1, S^2, S^3\} \times \{T_1, T_2, T_3\})$$

2.2 Notion of interoperable group (IG)

The table 1 describes an ideal case, because all systems of the set S are related to all themes of the set T.
Condition of openness :

$\exists\, i, t \mid S^i \in S$ and $T_t \in T$,
we have :
$(S^i, T_t) \subset R$.

Let :

$S :: \{S^i\}_{i=1,2,..,n}$,
$T :: \{T_t\}_{t=1,2,..,q}$,
$R \subset S \times T$
$S \in P(S)$
$T \in P(T)$

We define an (totally) interoperable group as :

$$IG :: < \text{\#-interoperable-group}(< s >\rho< t >) >$$

ρ means that R is a total relation on s x t, in other words, there exists only one dependency between the subset s and the subset t.

2.3 Openness structure of the coalition

We are presently formalizing the openness structure of a coalition C, through its dependant IG. For that purpose, let us consider this openness context of C:

	T_1	T_2	T_3	T_4	T_5	T_6
S^1	*	*			*	*
S^2		*	*	*	*	
S^3	*		*		*	

Tab. 2 Openness structure of the cooperation C

We will notice that this openness structure of C, is composed of 8 subsets. We obtain one after the other :

$$IG\text{-}1\ (\{S^1, S^2, S^3\}\ \rho\ \{T_5\}),$$
$$IG\text{-}2\ (\{S^1, S^2\}\ \rho\ \{T_2,T_5\}),$$
$$IG\text{-}3\ (\{S^1, S^3\}\ \rho\ \{T_1,T_5\}),$$
$$IG\text{-}4\ (\{S^2, S^3\}\ \rho\ \{T_3,T_5\}),$$
$$IG\text{-}5\ (\{S^1\}\ \rho\ \{T_1, T_2, T_5, T_6\}),$$
$$IG\text{-}6\ (\{S^2\}\ \rho\ \{T_2, T_3, T_4, T_5\}),$$
$$IG\text{-}7\ (\{S^3\}\ \rho\ \{T_1, T_3, T_5\}),$$
$$IG\text{-}8\ (\{\varnothing\}\ \rho\ \{T_1, T_2, T_3, T_4, T_5, T_6\}).$$

Let us construct now the diagram with the different IG we previously determined.

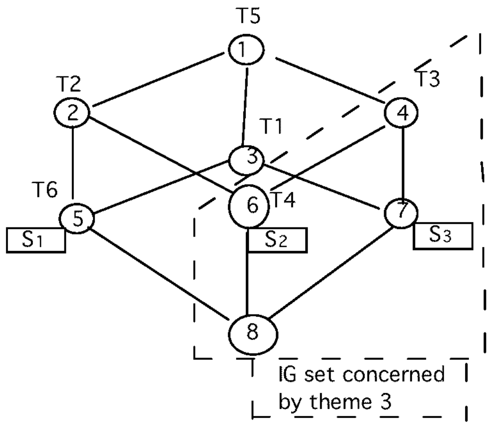


Fig. 4 Open structure formalization (OSC)

Fig. 4, which formalizes the openness structure of the cooperation C, presents a great deal of interest. From this diagram, we can interpret easily the openness structure when considering the following points :

- Every IG indexed by a number inherits all themes linked up to it in the diagram.
- Every node number is constituted of all the systems which are linked down to it.

3 Interoperability space

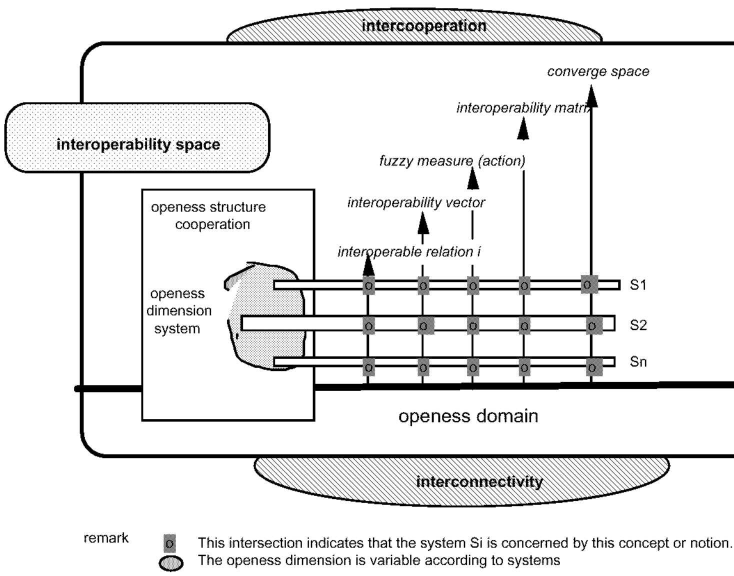


Fig. 5 Interoperability space

We will consider that an action is not interoperable in itself, but only with system(s) that are able to handle it. For that reason, we will always designate an interoperable action by a couple :

$$(S^k, A_j) \text{ where } S^k \in \{S^1, S^2, \ldots, S^n\}$$

Remark : This couple : (S^i, A_j) must encompass time variable (reification), because systems, and more actions, are likely to modify in run time. We will consider that its validity will depend on a temporal window or « window opportunity », which will be denoted as follows :

$$(S^i, A_j, \theta_M),$$

the system i acts (or (inter)operates) on the action j, in the temporal interval θ, assigned to the mission M.

The time parameters will be fixed by those who are in charge of the coalition.

3.1 Fuzzy Measure of an interoperable action

A fuzzy measure refers to a means of expressing uncertainty when, not disposing of complete information, it is impossible to use probability. We are going to determine numerical coefficients, or **certainty degrees**, to indicate how it is **necessary** that such a system can interoperate on (or with) such an action beforehand declared as **possible**. In doing the (reasonable) hypothesis that a system only executes one interoperable action at a time, we can for instance, form a **universe W** from the following singletons :

$W = \{(S^i, A_1), (S^i, A_2), (S^p, A_3), ...,(S^q, A_n)...\}$, with : $d(S^i, A_n)$ :: degree of possibility

$d(S^i, A_n) \in [0, 1]$, this value assesses the possibility which S^i executes the action A_n.

A fuzzy measure is completely defined as soon as a coefficient of possibility has been attached to every subset of a **universal set U**. If the cardinal number is n, to be rigorous, we must state 2^n coefficients, in order to specify the measure of possibility. Here, we will proceed more simply in observing that each subset of U may be regarded as an union of singletons it encompasses. So, the determination of the possibilistic measure can be done from only n elements. So, to define an interoperable action we here introduced :

(a) A **feasibility** measure comparable to a possibility,

(b) A **imperativity** comparable to a necessity which will be dual of (a),

(c) A **credibility** measure to assess trust put by systems in the fulfillment of an action by anyone of them.

(a), (b), will be defined thanks to distributions of possibility. Therefore we will represent an interoperable measure in a “fuzzy cube”.

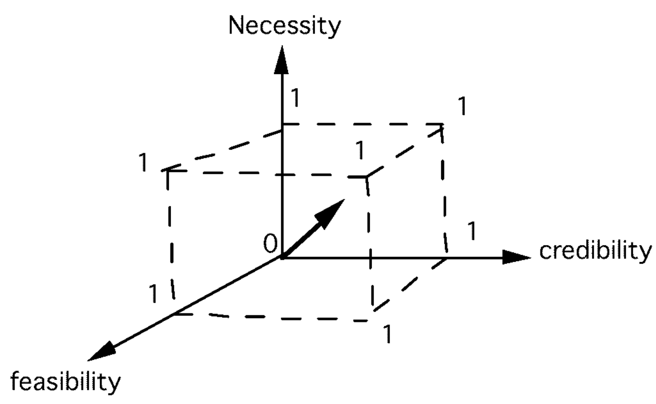


Fig. 6 Fuzzy representation of an interoperable action

3.2 Interoperable competence relation

Presently we define a **relation** $\Re$, in a propositional calculus view, the arity of which is 3, and by which any system gauges its aptitude to operate an action of the coalition. This relation must be applied by every system to every action of the cooperation. It will be denoted as follows :

$\Re$ :: «is able to (inter)operate» , we form the proposition : $\Re(S^i, \{A_j\}, \theta_M)$,
$\forall\, i \in [1, n]$, (n : number of systems)
$\forall\, j \in [1, p]$, (p : number of actions)

Remark :
S^i considers that it is competent to interoperate on $\{A_j\}$,
all Aj can be described with words of a formal language

Each system is bound to determine a first condition, **necessary** but not **sufficient** of its interoperability. According to its own knowledge and truths about its neighboring world, a system is able to say if such an action is normally interoperable. In fact, the relation $\Re$ which allows to define an **effective interoperability** : a system S^i gauges its competence to operate on any action, in window time θ attached to the mission framework M, under normal and usual conditions.

As $\Re(S^i, A_j, \theta_M)$ is considered like a proposition,
so we can assign a truth value to it :
if Value(Val) $[\ \Re(S^i, A_j, \theta_M)\ ]$ :: True (T/1)

that means :

S^i can interoperate on A_j, in time window θ, fixed by
mission M. $\forall\, i \in [1, n]$, $\forall\, j \in [1, p]$
Val $[\ \Re(S^i, A_j, \theta_M)\ ]$ :: False (F/0)
$\Rightarrow$ **interoperable incapacity** of S^i on Aj.

Remark : In practice, those who responsible for S^i are entitled to apply this relation, and thus, to decide about the interoperable (in)capacity of their interoperability .

3.3 Matrix of interoperability

For a given system S^i, If we successively apply the relation $\Re$ to couples (S^i, A_j), j varying from 1 to p, we obtain for example:

Val $[\Re\ (S^i, A_1)\ ]$ :: T
Val $[\Re\ (S^i, A_3)\ ]$ ::: F
....
Val $[\Re\ (S^i, A_p)\ ]$ :: T

Tab. 3 Application of the relation of interoperability

We bring together these elements in order to get a binary vector. There are as many vectors as systems in the coalition.

Let a component of vector $V(S^i)_j$ (row j), if we have :

val [$V(S^i)$]$_j$ :: F

$\Rightarrow$ $\neg\exists\Re$ (S^i, Aj) for openness structure of the coalition, and therefore, S^i has no semantics to evaluate, [V (Si)]j is not supposed to exist.

From the binary vector, or from the world resulting of the interpretation $\Re$, it becomes possible to affect fuzzy measures to each vector's components whenever the value is not false. These fuzzy vectors will be established in the following conditions :

We take:

either couples of the world $\Re$, such as : $((V(S^i)_{j=1,2,..p}) :: 1$,

or vector's elements $V(S^i)$, such as : $[[V(S^i)_{j=1,2,..,p}]](\Re) :: 1$

We assign a fuzzy measure to them, respectively corresponding to 3 dimensions, as described in 3-1:

Φ (S^i, Aj) $\rightarrow$ measure of feasibility,

N (S^i, Aj) $\rightarrow$ measure of necessity,

λ (S^i, Aj) $\rightarrow$ measure of credibility.

. $i \in [1, n]$, $j \in [1, p]$

Every system is able to establish its own interoperability vectors.

whenever for $j \in [1, p]$, val $V(S^i)_j = T \rightarrow$ semantics evaluation to do.

This evaluation of the semantics has been made necessary because : either unpredictable facts arrived in the own system's world or an unexpected mission could have modified the world of S^i; which means that Aj has no longer the same meaning for the system S^i and possibly also for the coalition. In gathering all vectors of interoperability $V(S^i)$, we get this way, what call an **interoperability matrix**.

$[I(S^i)_{i=1,2,..,n}] = [V(S^1)\ V(S^2) ......V(S^n)]$

This matrix represents only an apparent interoperability. It can be used in different ways :

- to indicate what is theoretically the most interoperable system, relatively to a determined action,
- to give most the adequate system to operate under special conditions : a mission which imposes a temporal constraint to operate an action. We will construct three kinds of interoperability matrices.

a) Matrix of feasible interoperability

This matrix gives a dimension of feasibility of the interoperability of the federation $\{S^i\}$ will be denoted by :

$$[I\text{-}\Phi(S^i)_{i=1,2,\ldots,n}]$$

b) Matrix of imperative interoperability

The matrix of necessary interoperability is also constructed with fuzzy vectors of necessity as described above. It presents a great interest in informing us about necessary conditions which are imposed to some systems in their way of interoperating. This matrix will be denoted by :

$$[\ \text{I-N}\ (S^i)_{i\,=\,1,2,3}]$$

Example with 3 systems and 4 actions :

$$\left[I - N(S^i)_{i=1,2,3}\right] = \begin{bmatrix} 0.8 & 0.8 & 0.0 \\ 0.0 & 0.6 & 0.8 \\ 0.8 & 0.0 & 0.6 \\ 0.8 & 0.6 & 0.8 \end{bmatrix}$$

Tab. 4 Matrix of imperative interoperability

We observe that in the previous matrix, system 1 must have the strongest interoperability in spite of its component $V(S^i)_{2,1} = 0$, which can incidentally indicate an interdiction to interoperate on action A_2.

c) Matrix of credible interoperability

This matrix gives us a visibility on systems which are about in the best position to interoperate successfully. It will be denoted by :

$$[\ \text{I-}\lambda\ (S^i)_{i\,=\,1,2,..,n}]$$

Example with 3 systems and 4 actions :

$$\left[I - \lambda(S^i)_{i=1,2,3}\right] = \begin{bmatrix} 0.3 & 0.0 & 0.3 \\ 0.0 & 0.0 & 0.3 \\ 0.8 & 0.3 & 0.3 \\ 0.3 & 0.6 & 0.3 \end{bmatrix}$$

Tab. 5 Matrix of credible interoperability

We observe that in this example, system 2 presents small degrees of credibility; this means that all systems consider that it is likely to be the least successful in the cooperation.

4 Cooperability domain

In this paragraph, we will try to go beyond the system's interpretation regarding actions and to see how any systems can interpret the other systems' ability for interoperating on actions. What one can summarize simplistically :

(1) interoperability (S^i) $\rightarrow$ system S^i interprets [S^i (interoperability) / {action(s)}], $\forall$ i $\in$ [1, n]
(2) intercooperability (S^i) $\rightarrow$ systems {S^k} interprets [(S^i) interoperability /{action(s)}], $\forall$ i, k $\in$ [1, n]

We can still illustrate (1) and (2) in an explicit manner :

(1) for the domain of interoperability :

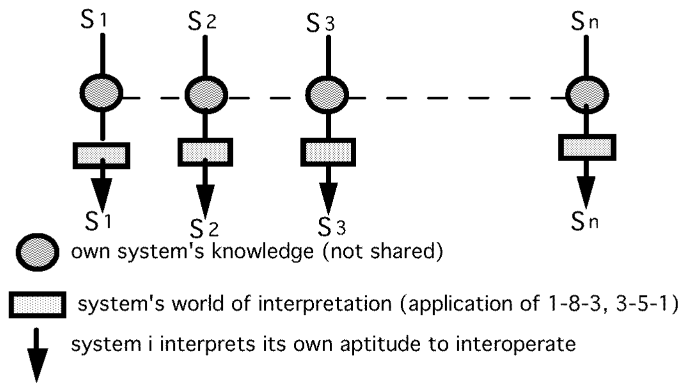


Fig. 7 Interpretation in the interoperability domain

(2) for the domain of intercooperability :

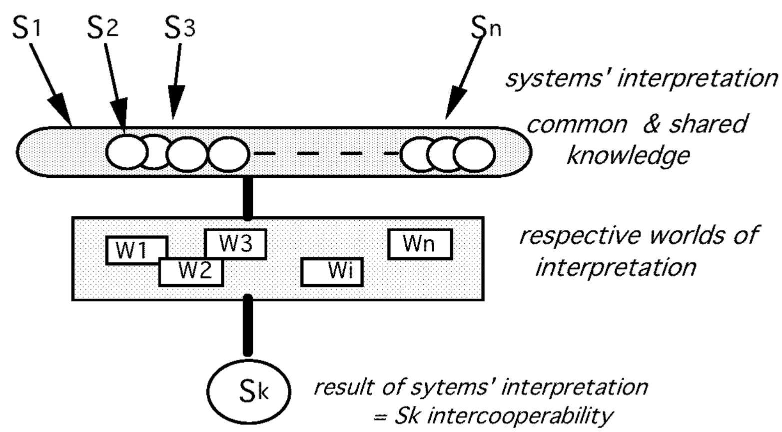


Fig. 8 Interpretation in the intercooperable domain

4.1 Intercooperability competence relation

So, what is going to get more important for systems in intercooperation it is the necessity to satisfy a permanent need of **mutual understanding**. In a practical way, that means they must :

- either share the same meaning relatively to the different objects they have to handle in their common universe's actions,
- or to take necessary steps to make **semantics** converge.

When defining the relation of the interoperability competence in 3.2, we have considered that systems, obviously placed in a symbolic context are able to interpret their own ability to interoperate on actions as requested by the coalition. In this paragraph we are now envisaging to go beyond, by seeking to extend the system's interpretation ability in defining a **relation of intercooperability competence**.

We will consider that a system S^i has a competence in intercooperability when, it will be able to "judge" the ability of adjoining (cooperative) systems to interoperate on a set of actions $\{A_j\}$, in a time window θ, fixed by a mission M. This competence will be designated by the following quadruplet :

S^i / S^k, $\{A_j\}$, θ_M (the symbol / indicates the way of interpretation) $\forall i$, $k \in [1,n]$, $j \in [1, p]$

We will define a relation of intercooperable competence in the same way we do for the interoperability competence, this one will be designated by $\Re'$, in the following conditions :

$\Re'$ :: « is able to (inter)cooperate »

$\Re'$ :: « interpret the other systems' aptitude to interoperate on $\{A_j\}$ », we form the predicate relation :

$$\Re' [S^i / (S^k, \{A_j\}, \theta_M)] \ \forall i, k \in [1, n], \forall j \in [1, p].$$

This means that : S^i judges that (confidence in the success of) S^k is able to interoperate on {Aj} in the time-window θ_M (this evaluation is made with a fuzzy measure of credibility).

In a predicate calculus view, the relation $\Re'$ defined in these conditions, is equivalent to a **propositional function**:

S^i, S^k, A_j, representing the variable, θ_M may be considered here as a constant [2]. So, for a given S^i, we can evaluate the truth value of the predicate :
S^k is interoperable on each $A_{j=1,2,..,p}$

(1) if *Val* $[\Re'[S^i / (S^k, \{A_j\}\theta_M)]$ :: True,
that means : S^i interprets that S^k is able to interoperate on the actions $\{Aj\}_{j=1,\ldots,p}$,

(2) if *Val* $[\Re'[S^i / (S^k, \{A_j\})]$ :: False,
S^i considers that S^k is unable to interoperate on$\{Aj\}j = 1,\ldots,p$,

Nota bene : θ_M has been considered as a constant in (1) and (2), for previously mentioned reasons.

4.2 Vector of intercooperability

As we do in 3-3 (for the vector of interoperability), for a given system S^i , we are going to apply the relation $\Re'$ successively to tuples :

$$S^k / (S^i, A_j, \theta_M)\ j = 1,\ldots,p.$$

As we continue to consider θ_M a constant in the predicate relation, from now we will simply consider the triplet :

$S^k / (S^i, A_j)\ j = 1,\ldots,p$

on which we can apply the predicate calculus rules. For instance, we shall obtain :

$$\text{Val } [\Re' (S^i / (S^k, A_j)_{j=1}] :: 1$$
$$\text{Val } [\Re' (S^i / (S^k, A_j)_{j=2}] :: 0$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\text{Val } [\Re' (S^i / (S^k, A_j)_{j=p}] :: 1$$

Tab. 6 Definition of an intercooperability vector

[2] We make the hypothesis that the time-window's limits are well defined in the cooperation. This hypothesis cannot be maintained if we are not sure of this fact.

Let us keep in mind that the letter p corresponds to the maximal number of actions in the coalition. In bringing together these elements we obtain a binary vector, called the **vector of intercooperability**, will be designated by :

$$V\,(S^i\,/\,(S^k, A_j))_{j\,=\,1,..,p;}\;\; k \in [\,1,\,n\,].$$

4.3 Matrix of intercooperability

In gathering the vectors of intercooperability, we will get what we are now calling an **intercooperabilility matrix**. Although the interoperability matrix is unique, it is necessary to establish two categories of matrices in the domain of intercooperability.

1) The first category, called intercooperability-system, is going to indicate how the set of systems interpret their respective interoperability .
2) The second one, called intercooperability-action, is regarding actions, i.e. a matrix to comprehend the interoperability of the cooperation from its actions.

4-3-1 Matrix of intercooperability-systems

Now the question is to comprehend how the federation of systems, interprets the ability of interoperating one of them. Let us keep in mind that all systems are more or less interoperable according to the other systems' judgment. The intercooperability matrix of a system S^i will be denoted : **[C(S^i)]** and presents a great interest. In fact, we can make special computations about rows and columns of **[C(S^i)]**. Therefore, we obtain some interesting elements to characterize what we are going to call **intercooperable capacity** of the cooperation, i.e. the visibility about the more or less easiness of system's interoperation.

Properties of a column

Let [C(S^k)] be the matrix of intercooperability-system of the system S^k, and consider the m^{th} column of this matrix. If we sum up all components of the **vector column m** of the matrix [C(Sk)], we are going to get a certain scalar, designated by : $\alpha_c\left(S^k\right)$.

$$\alpha_c\left(S^k\right) = \sum_{j=1}^{p} \left[C(S^k)\right]_{j,m}$$

4.3.2 Matrix of intercooperability-action

We now define an other kind of matrix which is going to allow us to have a visibility of the intercooperability of all systems of the coalition. This special matrix is going to indicate what are the systems which are in the best conditions to interoperate on actions. These matrices will be called **matrix of intercooperability-action** for that reason**.** Let us go back to the matrices of intecooperability-system; if we take the j^{th} row in each of the previous matrices, we are forming a new matrix that reports about the systems' intercooperability capacity relatively to the action A_j. This matrix will be designated by [C(Aj)].

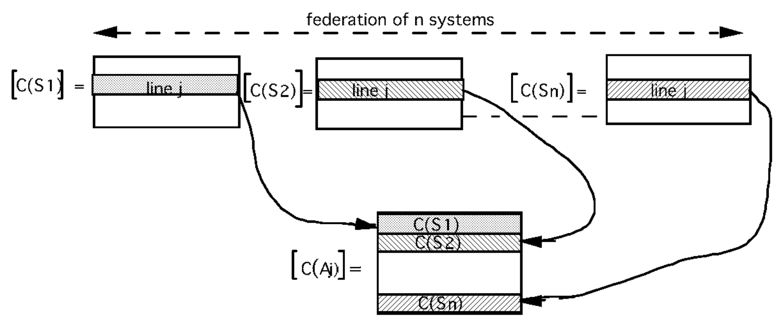


Fig. 9 Matrix of intercooperability-action

The matrix of intercooperability-action presents interesting features :

- its shape is square,
- it allows to understand what are the systems of the federation which are in the best position to interoperate on such an action A_j,
- it gives an idea about the lesser or greater systems' easiness to interoperate on particular actions,
- its columns and rows have interesting characteristics.

If we compute the p matrices corresponding to all actions of the coalition, we have a good visibility of the intercooperability in the coalition framework. That means we are able to say :

- what are the actions which are difficult to carry out,
- what are the ones which are likely either to get the coalition into trouble or to force the cooperation to face difficult issues.

5 Conclusion

In this paper, we have introduced notions of openness context and interoperable group. We have afterwards demonstrated that it was possible to formalize the structure openness of a federation of systems (representing the coalition). Then we have defined a notion of an interoperable action to which we have attached fuzzy measures **: feasibility, imperativity, credibility (**determined through distribution of possibility). By introducing a relation of **interoperability competence**, we have shown that it was possible to construct a vector of **effective interoperability**, resulting of the system's interpretation of the facts in its own logic world. In this way, we got a quantitative evaluation of interoperability pertaining to a system of the coalition. These vectors of interoperability define a **matrix of interoperability** which gives a right visibility about the global interoperability pertaining to the set of all systems of the coalition. We afterwards went beyond this ability of a system to interpret its own ability of interoperating and to see how it could interpret the other systems' ability for interoperating on actions. For that purpose, we have introduced a relation of intercooperability competence, defined in a predicate calculus field, which may be regarded as an extension of the relation of interoperability: this relation enlarges our comprehension field about the interoperability of the others. We establish two kinds of matrices; the first one regarding the systems' interoperability, the other one concerning the actions. These matrices present interesting properties, which have allowed us to establish a whole family of parameters, and doubtless represent a first significant step in our way of seeing the interoperability issue.

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